

## EBB-TIDAL DELTA DEVELOPMENT WHERE BEFORE THERE WAS NONE, SHARK RIVER INLET, NEW JERSEY

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**Abstract:** The navigation channel at Shark River Inlet, NJ, is the responsibility of the U.S. Army Corps of Engineers, New York District. Until about the year 2000, the ocean entrance to Shark River Inlet required minor, infrequent maintenance dredging (every 7 to 10 years). Following large-scale beach nourishment to this stretch of coast in the late 1990s, the hydraulically efficient inlet began to experience rapid shoaling at the entrance. Subsequent to year 2000, surveys by the New York District indicated increased shoaling at the inlet entrance, first from the south and then from the north, necessitating unplanned dredging to maintain the navigation channel. To maintain the authorized entrance channel navigable depth of 5.5 m below MLW, dredging must now be done semi-annually in addition to the planned operational 2-3 year dredging cycle. A study was performed to understand and quantify the reasons for change in the inlet morphology and increased channel shoaling, and to predict the consequences of future engineering actions for reducing or controlling the shoaling. Formation and growth of an ebb-tidal delta at the entrance subsequent to the beach nourishment is documented, before which there was none.

### Introduction

As part of the Sea Bright to Manasquan Inlet Beach Erosion Control Project, in 1997 the U.S. Army Corps of Engineers (USACE), New York District, placed approximately 4.1 million m<sup>3</sup> of fine to medium sand to the south of Shark River Inlet, NJ. Thirteen long groins in Belmar and the Borough of Spring Lake, located south of the inlet, were notched (lowered in elevation) in 1997 and 1998 near the shore to promote sand movement into a local erosion hot spot. During 1999-2000, another 2.4 million m<sup>3</sup> of sand was placed to the north of the inlet, and, in the autumn of 2002, another 172,000 m<sup>3</sup> of was placed north of the inlet (Bocamazo et al. 2003; Donohue et al. 2004).

Until about the year 2000, the ocean entrance to Shark River Inlet required minor, infrequent maintenance dredging (every 7 to 10 years). The General Design Memoranda for the Erosion Control Project (USACE 1989, 1994) anticipated increased shoaling and a shorter time interval between dredging at the Shark River Inlet entrance to approximately every 2 to 3 years owing to increased availability of sand. Following the large-scale beach nourishments, however, the formerly

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hydraulically efficient inlet began to experience rapid shoaling at the entrance. Subsequent to year 2000, surveys indicated increased shoaling at the inlet entrance, first from the south and then from the north, necessitating unplanned dredging. To maintain the authorized entrance channel navigable depth of 5.5 m below MLW, dredging must now be done semi-annually in addition to the planned operational 2-3 year dredging cycle. A study was performed to understand and quantify the reasons for change in the inlet morphology and the increased channel shoaling, and to predict the consequences of future engineering actions for reducing the shoaling.

## Background

Shark River Inlet is located in Monmouth County along the Atlantic Highlands region of the north-south oriented New Jersey shore (Figure 1), is situated between Sandy Hook, located approximately 30 km to the north, and Manasquan Inlet located 10 km to the south. The inlet is served by a federally-maintained navigation channel connecting the small estuary of Shark River, with limited freshwater flow, to the Atlantic Ocean. Tide in the area is predominantly semi-diurnal with a spring range of 2 m and neap range of 1 m. Energetic waves arrive out of the north in winter, whereas summer waves are typically calmer yet consistent in height, period, and direction from the south. Shoreline orientation, wave sheltering from Long Island, and the seasonal wave pattern typically produces a net longshore sand transport to the north (USACE 1954, 2006; Angas 1960). Angas (1960) documents that the south (up-drift) jetty impounded a considerable sand volume along the adjacent beach during the late 1950s, and noted that a bar tended to form around the south jetty, directed to the north.

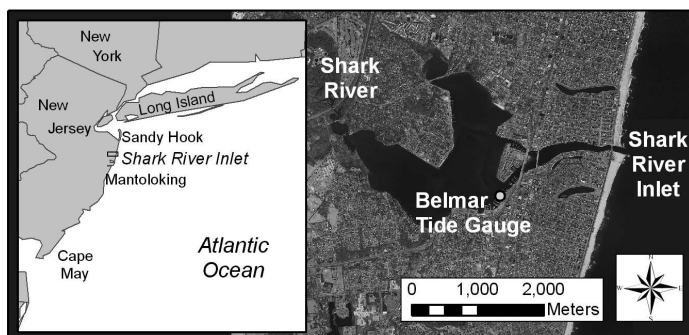


Figure 1. Location map for Shark River Inlet, NJ.

The northern Atlantic coast of New Jersey has experienced a severe sand deficiency for the past century, resulting in loss of beaches, placement of dense numbers of sand-retention structures, and overall winnowing of finer sand to leave a coarser lag (Kraus et al. 1988). Sediment, primarily consisting of sand along the nearshore and

beach face, originates from reworked glacial material and has an average grain size ranging between 0.2 and 0.35 mm with a median grain size diameter of 0.26 mm for the average nearshore profile (Kraus et al. 1988). The beach profile has tended to steepen in approach to equilibrium with the coarser sand. Based on a regional sand budget, the long-term net potential longshore sand transport rate has most recently been estimated at 153,000 m<sup>3</sup>/year to the north, with the gross transport rate at 696,000 m<sup>3</sup>/year (USACE 2006). The gross transport rate at the site, the sum of the north- and south-directed rates, contributes to shoaling of littoral material into the navigation channel. Long-term net and gross sand transport rates correspond to potential longshore transport and can be realized only if sand is fully available to be transported in the littoral zone. Littoral material will bypass the channel as well as deposit in it, because shallow channels are not complete traps to littoral transport, especially during storms.

Shark River Inlet is stabilized by two parallel rubble stone jetties owned and maintained by the State of New Jersey. Two curved jetties were constructed in 1915, and between 1948 and 1951 the State rebuilt and realigned the jetties to extend straight to the ocean (Angas 1960), adding a 152 m-long shore-parallel external spur of the north jetty (Figure 2). The federal navigation project consists of the entrance channel, which is 5.5 m deep (MLW) and 45 – 60 m wide from the Atlantic Ocean to the inlet throat (Figure 2). The inlet, connecting the estuary of Shark River to the ocean, is 60 m wide at the narrowest section where one bridge crosses, held up by two pilings, and decreases to 40 m in the north flood channel and 100 m in the south flood channel. Several shallow and intertidal, oyster-encrusted shoals increase the flow resistance in addition to two bridges spanning this section (each with five to ten small piers spanning the channels). Material dredged from the inlet entrance, consisting of beach-suitable sand, is bypassed to an open-water disposal site located offshore between the second and third groins located 0.6 and 1.0 km to the north of the inlet. The upper right-hand corner of Figure 2 depicts the placement locations from a December 2007 dredging and disposal.

The entrance to Shark River Inlet serves a relatively small estuary complex with a tidal prism of  $4.19 \times 10^6$  m<sup>3</sup> (Jarrett 1976), channel cross-sectional area of  $2.79 \times 10^3$  m<sup>2</sup>, and inlet entrance width to depth (hydraulic radius) ratio of 17, one of smallest of 108 U.S. inlets and the smallest among 35 Atlantic coast inlets tabulated by Jarrett (1976). Beck and Kraus (2010) performed a harmonic analysis for the month of August 2009 at the nearby ocean tide gauge at Sandy Hook, NJ, and a bay-side tide gauge at Belmar, and found small tidal attenuation and phase difference. This hydraulic efficiency owes both to its small width to depth ratio and to negligible impedance from bottom features such as sand waves in the channel entrance.

According to the empirical relation of Walton and Adams (1976), the tidal prism at Shark River Inlet can support an ebb-tidal delta of  $0.92 \times 10^6 \text{ m}^3$  at dynamic equilibrium, if sand is available to form and maintain this feature. Davis and Hayes (1984) characterized barrier tidal-inlet morphology according to tidal range and average incident wave height. Inlets on the coasts of northern New Jersey and Long Island tend to be wave dominated, as opposed to tide dominated, illustrating an ebb delta that is roughly horseshoe shaped around the entrance. Formation of ebb- and flood-tidal deltas is normally calculated as part of the sand budget developed in planning of new inlets to be opened, and the need for accounting for such a new sand volume at an existing inlet is unusual. Approaching maturity or equilibrium volume, an ebb delta will naturally bypass most of the sand arriving to it unless intercepted by a maintained navigation channel, which would trap some portion. That portion can be bypassed mechanically or hydraulically during channel maintenance.

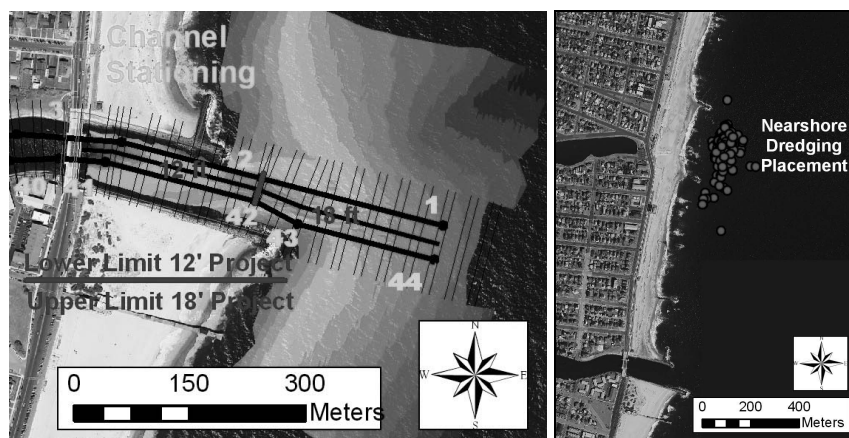


Figure 2. Left: Navigation project at Shark River Inlet; Right: Nearshore dredging placement (2007).

## Procedure

A GIS analysis was made of aerial photographs, dredging activities, and the evolving ebb-tidal delta. The first set of surveys from 1995, 1998, 1999, and 2000 were channel condition surveys, increasing in frequency following the 1997 beach nourishment. After the condition survey of May 2000, before- and after-dredging surveys increased significantly in regularity to twice a year because the channel began to shoal more frequently. The survey data are analyzed to determine short-term shoaling rates and long-term ebb-tidal delta evolution over the past 15 years.

These data were employed to establish the Coastal Modeling System (CMS), a coupled numerical model of waves and finite-volume, depth-averaged circulation,

sediment transport, and morphology change (<http://cirp.usace.army.mil/>). The CMS was driven by tide and hindcast waves. The Non-equilibrium Transport model, based on a total load advection-diffusion approach, was selected to calculate sediment transport rates in CMS-Flow. Two CMS grids, one for CMS-Wave and the other for CMS-Flow and sand transport, cover the same alongshore distance of 8.5 km and a cross-shore distance extending from the land seaward to the ocean boundary of 3.5 km (Figure 3). The finest resolution of the model grid cells was set to 8 m in the inlet throat and the bay, and 16 m in the bay and ebb-tidal delta and nearshore. Maximum cells sizes in the bay reached 120 m over large open bay expanses, and to 240 m along the offshore boundary.

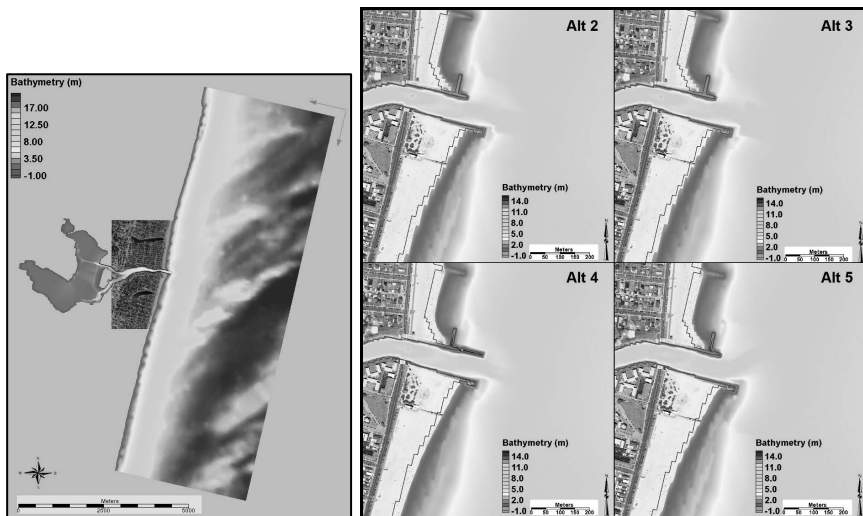


Figure 3. CMS modeling domain for Shark River Inlet (A), and Alternatives 2-5 (B).

An existing condition from a recent January 2009 bathymetry formed the basis to generate a grid for contemporary representation of the inlet after dredging (Figure 3). This grid was part of model calibration to morphology change (Alt 1, a non-response alternative) and for the base bathymetry for Alts 2, 3, and 4. Alt 2 defined a widened dredged channel (“channel widener,” a type of advance dredging) 15 m on each side as recommended by Kraus and Allison (2009), and Alt 3 defines a widened dredged channel 30 m wide. Alt 4 examined a 75-m extension of the north jetty, making it parallel and equal in length to the south jetty. Alt 5 was based on the December 2008, before-dredging bathymetry, which has a naturally NE-SW trending channel orientation, and was modified to a depth of 5.5 m below MLW. All alternatives were simulated for 1 year of morphology change, and results of both the initial 4 months and full year are examined here.

## Results

### *Observed Geomorphology*

The bathymetric dataset analyzed covers 27 USACE surveys available from January 1995 to January 2010. Inlet shoaling rates are given in Figure 4, and Figure 5 includes several examples from the dataset, illustrating depth contour maps set to MLW and with the same horizontal scale. Surveys from the late 1990s indicate that the entrance channel was devoid of notable shoals and that the maintained navigation channel extended to deep water without evidence of a shallow deltaic platform (1995 survey in Figure 5). Surveys subsequent to the 2000 survey indicate a large shoal on either the north or south jetty tip. Such morphologic variation is attributable to seasonal changes in wave direction, where high waves incident from either the north or south, and their associated current, would transport sand along these shoals and into the channel, as seen in the July 2003 Condition Survey.

Figure 5 shows before- and after-dredging surveys of December 2002 and January 2003, and indicates the extent to which the channel is now dredged, on the order of 10,000-20,000 m<sup>3</sup> of sand. The 7 July 2003 survey demonstrates the quick reformation of the entrance bar, part of the horseshoe-shaped ebb delta morphology characteristic of wave-dominated inlets. As the nourishment material rebuilt both the up-drift (south) and down-drift (north) nearshore profiles alongside the inlet, the growing ebb-delta became more symmetric as seen in the May 2006 survey.

Shoal volume, plotted in Figure 4, increased over the past 10 years as compared to the May 1999 survey. The shoal volume was calculated over the channel stationing area between the jetties (Figure 2), from the Highway 1 bridge seaward to the 5.5 m contour depth (MLW). The total volume increase for the last decade, from May 1999 to April 2009, is calculated to be approximately 90,000 m<sup>3</sup> with 40,000 m<sup>3</sup> within the entrance channel and greater than 50,000 m<sup>3</sup> outside of the jetties. This analysis indicates recent shoaling rates on the order of 20-35,000 m<sup>3</sup> per year.

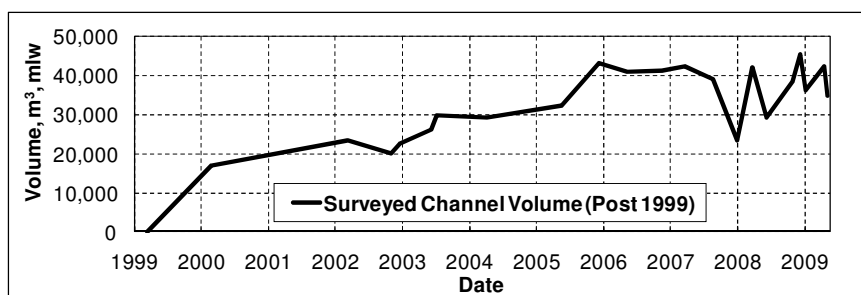


Figure 4. Volumetric change of the entrance channel to Shark River Inlet after 1999.

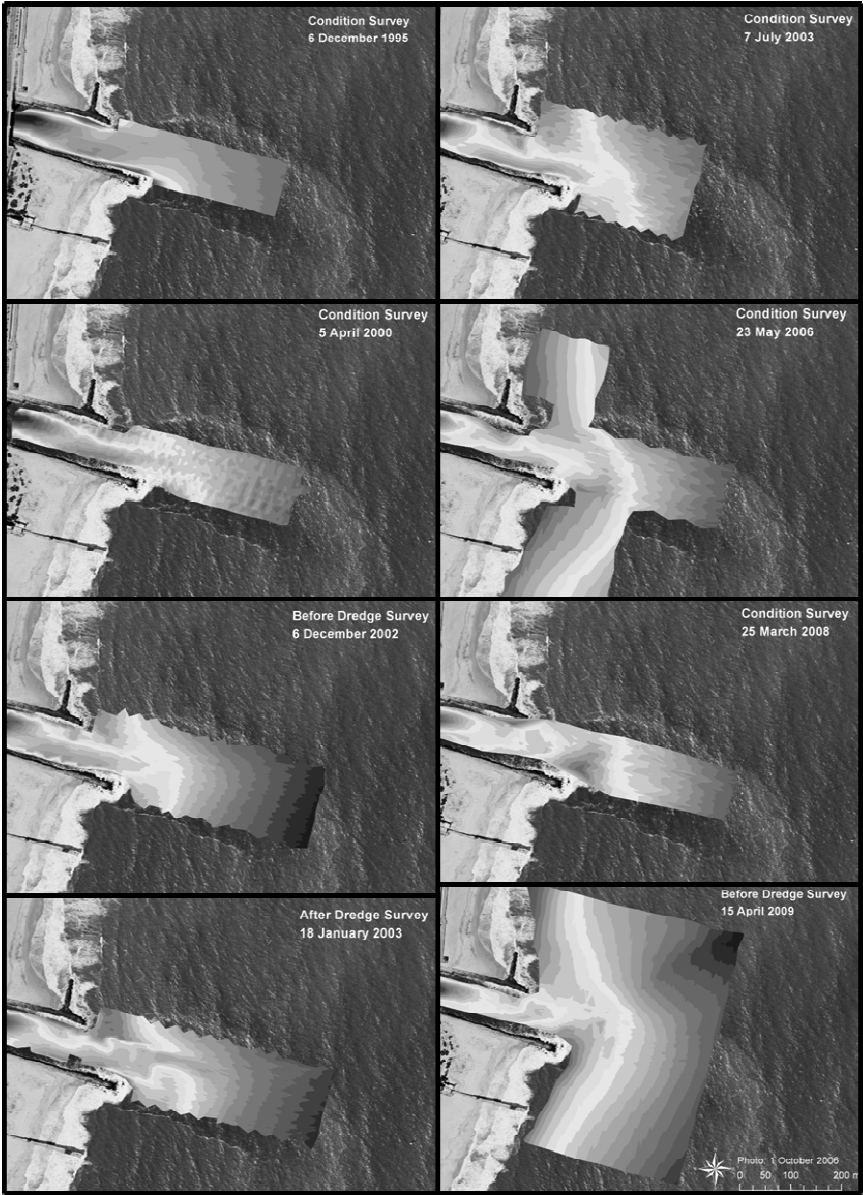


Figure 5. Shark River Inlet entrance, NJ, surveys from 1995 to 2009.

## CMS Morphologic Modeling

Calibration of the CMS for was completed in two parts: first, through comparison of measured and calculated hydrodynamics, and second through comparison of morphologic end-states through validating channel infilling rates and morphologic patterns. Observed water levels and measured current velocity in the Shark River estuary and inlet, collected on 20 August 2009, were used in the hydrodynamic calibration by Beck and Kraus (2010). Beck and Kraus (2010) also compared measured and calculated current velocity at the centrally-located peak velocity in the three main channels (Figure 6). Measurements and calculations show close correspondence for the main channel (CS 1) and south channel (CS 3) with a Root Mean Absolute Error (RMAE) value of 3-5%, and an RMAE of 9 % for the north channel (CS2).

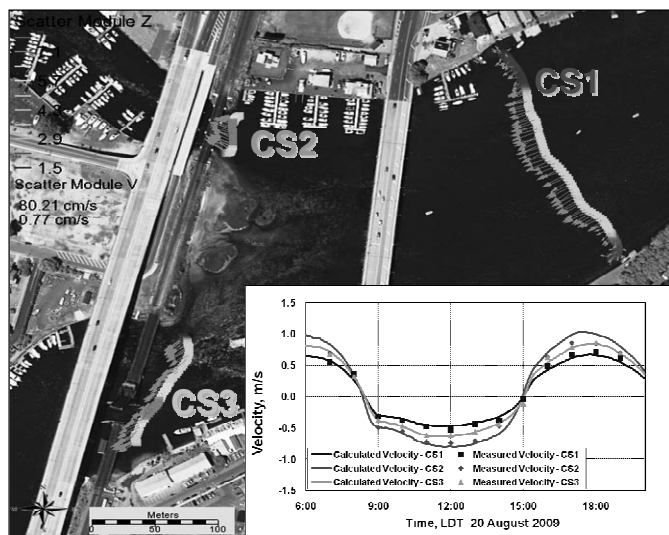


Figure 6. Measured and calculated current velocities at centrally-located points along surveyed cross sections (CS) shown in figure background (Beck and Kraus, 2010).

Morphologic response was calibrated to the measured change from January 2009 to April 2009, a typical recent dredging interval, and served to verify channel cross-sections and infilling rates (Figure 28). Based on the surveys, channel infilling volume expected for the 4-month simulation is 8,900 m<sup>3</sup> for the entrance channel alone. The 4-month simulation produced a similar channel infilling volume of 9,200 m<sup>3</sup> (RMAE of 3.4%) and morphologic patterns, as illustrated in Figure 7. A comparison of measured and calculated change along the transects in Figure 7 showed a high correlation with RMAE values of 7%, 11%, 2%, 4%, and 6% for Transects 1-5 respectively.

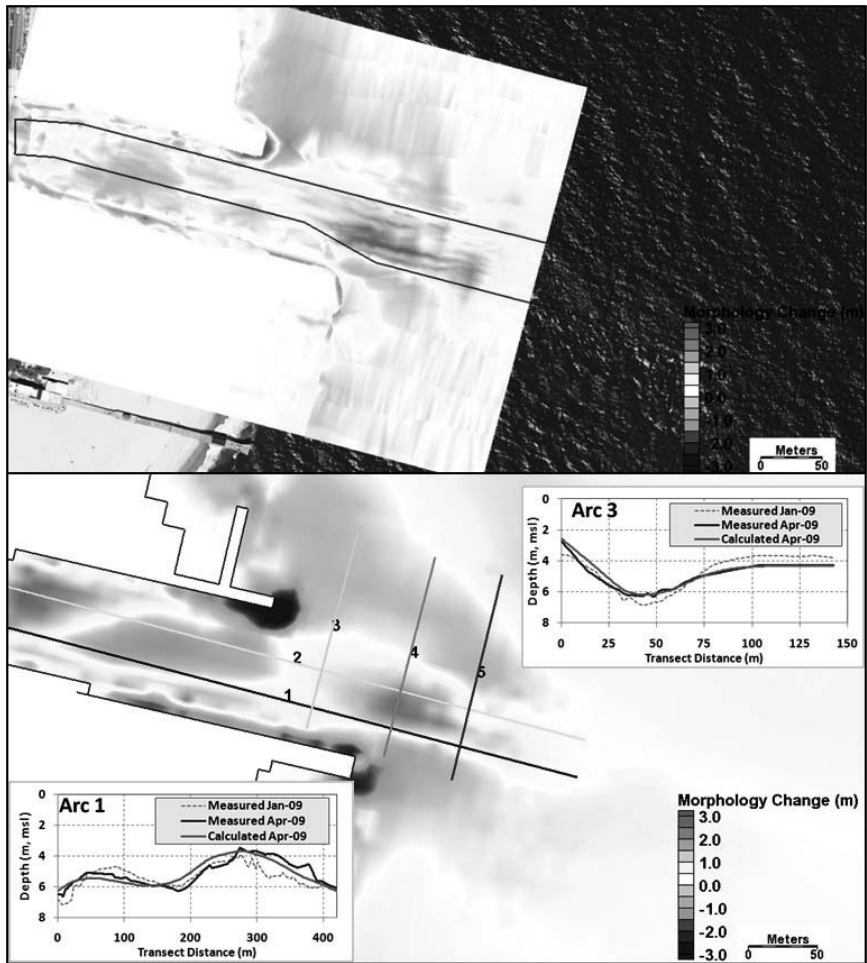


Figure 7. Measured (top) and calculated (bottom) morphology change at the entrance channel. Transects (arcs) 1-5 are illustrated on the calculated morphology with two examples graphs.

Under the two channel widening alternatives, Alts 2 and 3, there is a significant change in morphologic response by extending the dredging north and south of the authorized channel (Figure 8). Channel infilling volume for the 4-month simulation of Alt 2 and Alt 3 is greater by 5,000 m<sup>3</sup>; however, the limiting depth of the shoal in Alt 2 is only 5.3 m as opposed to 5.0 m. The proximal side of the channel is scoured greater (-7.0 to -9.0 m MSL) than the authorized depth. There is a large offset of channel orientation toward the north as a result of the greater volume of shoaling around the south jetty tip. In conjunction with the south shoaling, currents are no longer directed parallel through the channel, but meander under the influence

of both morphology and jetty configuration. A decrease in shoaling response for Alt 3 as opposed to Alt 2 was found after four to six months (Figure 8); however morphologic response essentially converged in both modeled alternatives.

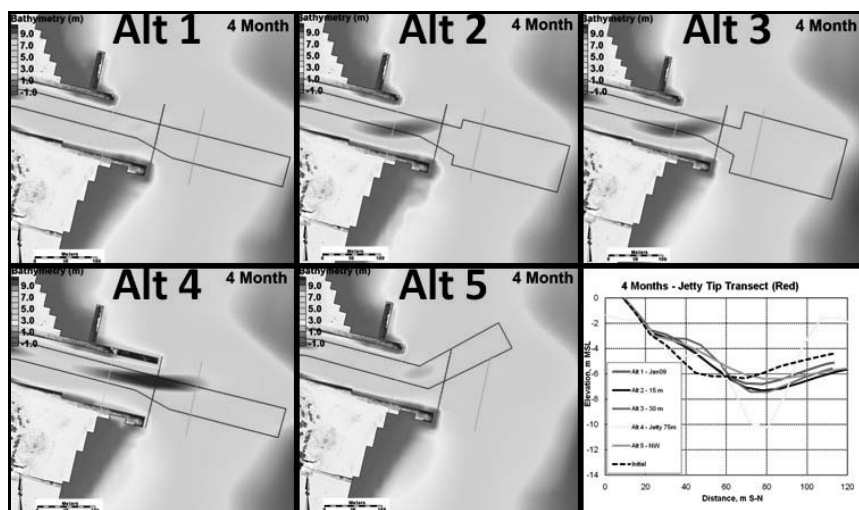


Figure 8. Calculated morphology change of 4 months at the entrance channel. The red Jetty Tip Transect (lower-right corner) gives cross-sectional depths.

Morphology change calculated for Alt 4 indicates a stronger along-channel current in the inlet, resulting in a clear and perpendicular-oriented channel (illustrated in Figure 8), scouring beyond the direct influence of the adjacent, shallow nearshore. The most dominant process controlling this morphology is the current pattern resulting from the confluence of ebbing and flooding currents over a longer extent of channel with parallel or straight boundaries. The extended straight boundaries decrease the potential for a meandering pattern, which was exacerbated in Alts 2 and 3, and produces stronger along-inlet current velocity, which maintains a deep and symmetric channel morphology. Finally, the channel slopes approach equilibrium under the new centrally-located stable and deeper channel and, as a result, a large volume of sand is deposited along the sides of the channel.

Alternative 5 was the least effective at maintaining navigable channel depths for a longer period of time as opposed to the present dredging practice (Figure 8). Although the initial channel morphology directed NE-SW for this alternative represents the present condition, volume of sand removed (under the dredging) is relatively small and, therefore, there is little accommodation space for the sand transported around the distal part of the ebb-tidal delta. The calculated result of this alternative is most similar to Alt 1, where no changes were made to the post-dredged bathymetry from January 2009.

## Discussion

CMS modeling reproduced a known seasonal dependence to shoaling in the area near the north and south jetty at Shark River Inlet, as well as the general trend of growth of the ebb-tidal delta and encroaching (jetty-tip) shoals. Here, we compare results of the 1-year simulations for four of the alternatives (Figure 9). Under the two channel widening alternatives, Alts 2 and 3, there is a significant morphologic response by extending the dredging outside of the channel. Under present dredged conditions, ebb current velocity is strongest through the maintained portion of the channel until deflected with the onset of channel shoaling. Because the location of shoaling is seasonal, advance dredging in the form of channel wideners affords the channel more time to remain clear of limiting shoaling from either north or south, of which begins outside of the tidal current influence and is evidently associated with wave-induced longshore transport. These alternatives are an effective solution with little additional cost as part of ongoing channel maintenance in lengthening the required time between dredging (reducing mobilization cost).

Channel wideners may also be considered as an interim solution that can be adaptively managed while further examining extension of the north jetty (Alt 4). Presently, the bypassing bar (or platform) is located close to the jetty tips and, because of the unequal lengths of the jetties, jetty-tip shoaling occurs in an asymmetric morphologic pattern of the entrance bar. The morphologic pattern is further modified by the orientation of the channel, where the direction of current in the form of the ebb jet acts in combination with the longshore current (Figure 9). Morphology change calculated for Alt 4 resulted in a self-scouring, perpendicular-oriented channel. Alternative 5 was the least effective at maintaining navigable channel depths for a longer period of time as opposed to the present dredging practice.

Nourishment placed on the adjacent beaches supplied the necessary volume of sand to establish a shallow sand platform as the base to initiate an ebb-tidal delta at Shark River Inlet. The platform formed in the early 2000s and serves as a pathway for sand to be transported around the jetty tips. Surveys from the past decade indicate a seaward expansion of the platform and further development of the ebb-tidal delta as the inlet evolves to dynamic equilibrium under a larger rate of sand transport. Dredging interrupts development of natural sand bypassing, reorients the channel, and resets the morphology to a condition that responds quickly to the increased sand transport. CMS alternatives discussed here provide quantitative information for evaluation of the efficiencies of potential engineering actions.

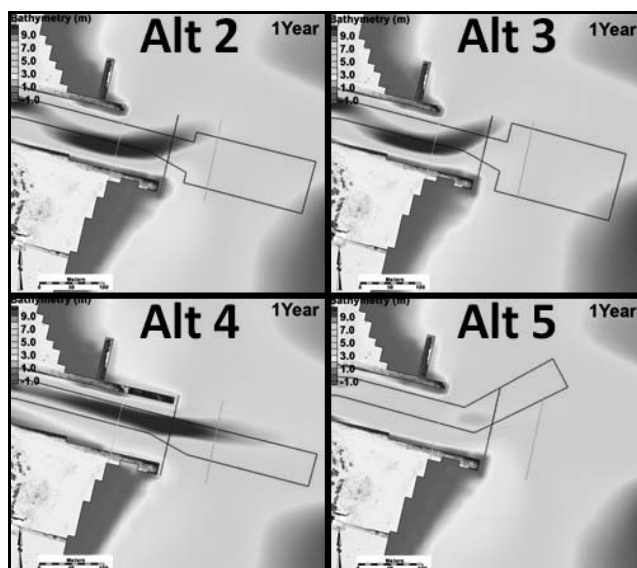


Figure 9. Calculated morphology change for 1 year at the entrance channel.

## Conclusions

For many decades, the entrance navigation channel to Shark River Inlet remained clear of significant sand infiltration with only minor sand shoaling in the entrance, so it was not a sink for beach sand. Natural sand bypassing must have occurred, but the limited supply did not allow formation of an ebb-tidal delta. Following the first beach nourishment on the south side of the inlet in 1997, sand began to build a platform for the entrance bar to develop off the tip of the longer jetty. It was not until 2000 that the northern nourishment was completed, after which notable channel shoaling began. In the context of the new morphodynamics at Shark River Inlet, planning with respect to long-term operation of the inlet must be carried out with concern for regional management. In particular, about one-fifth of the volume of material placed on the beach for the erosion-control project is expected to contribute to forming the ebb-tidal delta and must be accounted for in the sand budget. Considerably smaller-than-expected ebb volume (about  $90,000 \text{ m}^3$ ) suggests that the delta is competing with the existing over-steep beach profile for sand in the region. Also, dredging of the channel and bypassing the material to the north limits ebb delta growth.

The CMS, driven by tide and hindcast waves, was capable of reproducing observed trends in ebb-tidal delta development and changes in volume of notable morphologic features. The modeling system was verified by reproducing observed water levels in the Shark River estuary and current velocity in the inlet, and further

calibrated to morphology change for a 4-month simulation. The CMS was then applied as an example of evaluating selected alternatives for reducing dredging frequency in maintaining the inlet navigation channel. Channel wideners were found to be an effective interim solution with little additional cost as part of ongoing channel maintenance in lengthening the required time between required dredging events (reducing mobilization cost). Alt 4 (extended north jetty) predicts a stronger along-channel current in the inlet, resulting in a clear and perpendicular-oriented channel, scouring beyond the direct influence of the adjacent, shallow nearshore. This alternative provided the greatest overall change to the inlet system and was recommended as a long-term solution because of the benefit to navigation.

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